THE INFLUENCE OF SOME FACTORS ON CUTTING FORCE AND SURFACE ROUGHNESS OF WOOD AFTER SANDING

Ľ JAVOREK, J KÚDELA, J SVOREŇ… - Pro Ligno, 2015 - proligno.ro

Abstract This contribution presents results of an experimental research on sanding. With a sample of oak being the experimental material, sanding was carried out on radial, tangential and transversal surface of the piece. The impact force was changed on three levels (21 N, **...**

Articole cu conţinut similar Toate cele 5 versiuni Citați Salvați Mai multe

EFFECTS OF FOUR SURFACING METHODS ON SURFACE PROPERTIES AND COATING PERFORMANCE OF RED OAK WOOD

B Ugulino, RE Hernández - researchgate.net

ABSTRACT The performance of a coating on wood is influenced by many factors, including surface machining before coating. In an attempt to determine a suitable method of surface preparation for red oak wood, the effects of machining processes on surface properties **...**

Articole cu conţinut similar Citați Salvați Mai multe

EFFECTS OF FOUR SURFACING METHODS ON SURFACE PROPERTIES AND COATING PERFORMANCE OF RED OAK WOOD

Bruna Ugulino[1], Roger E. Hernández[1]
[1] Université Laval, 2425 rue de la Terrasse, Québec City, CANADA
bruna.oliveira.1@ulaval.ca, roger.hernandez@sbf.ulava.ca

ABSTRACT

The performance of a coating on wood is influenced by many factors, including surface machining before coating. In an attempt to determine a suitable method of surface preparation for red oak wood, the effects of machining processes on surface properties and coating performance were studied. Aside from two traditional surfacing methods preceding coating, sanding and peripheral planing, two alternative methods were evaluated: helical planing and oblique cutting. Surface quality was assessed through roughness, SEM and wettability analyses. Adhesion tests before and after an accelerated aging were carried out to evaluate the performance of a solvent-borne coating. Results indicated that sanding produced surfaces with the lowest roughness values. However, SEM analysis revealed that these surfaces had the highest cell damage, which was assumed to be responsible for increased surface energy and improved coating adhesion after weathering. Oblique cutting and helical planing produced surfaces with similar features. The highest loss in adhesion after weathering was founded on helical and peripheral planed surfaces. Furthermore, oblique cutting samples provided long-term adhesion strength similar to sanding.

Keywords: red oak wood, sanding, peripheral planing, helical planing, oblique cutting.

INTRODUCTION

Several factors affect the coating performance on wood such as surface preparation prior to coating. Red oak, one of the most valuable species in the North America, is largely used for furniture, flooring, interior trim, and veneer. Thus, knowledge of the effect of different surfacing methods on these surfaces in order to improve its preparation and enhance the coating adhesion is of great interest. The most common surfacing method prior to wood coating is sanding. However, this process is one of the most skill-based, time consuming, and expensive operations in wood industry (1). Peripheral planing is a common machining process in woodworking and provides a good surface finish. Helical planing could be used in order to reduce dependence on sanding and improve surface adhesion. Previous study has reported that helical planing provides surfaces with improved wetting properties, good fibrillation, and virtually no cell crushing (2). Oblique cutting produces surfaces virtually free of cell crushing (3).

Wood surface properties affect application and performance of wood coatings (4-5). One important characteristic to assess the quality of machined wood surfaces is the process roughness which can be related with coating performance. However, roughness alone cannot completely describe the machined surfaces. Scanning electron microscope (SEM) micrographs are often used as a qualitative analysis of machined wood surfaces and can corroborate with surface roughness evaluation. Another important analysis that provides valuable information about the coating performance is the wetting behaviour of wood surfaces prior to coating. Wetting of the surface by an adhesive is a necessary prerequisite to bond formation (6). Coating performance can be assessed through adhesion strength and weathering tests. Adhesion strength is measured by several methods such as pull-off method. Accelerated weathering test provides valuable information about durability of wood-coating system in a shorter time than natural weathering. In this context, the purpose of this study was to investigate the effect of four surfacing methods on red oak surfaces regarding surface properties and coating performance.

MATERIALS AND METHODS

Material

One hundred twenty kiln dried boards of red oak (*Quercus rubra* L.) wood were used in the present study. Before planing, boards were stored in a conditioning room at 20°C and 40% relative humidity (RH) until they reached 8% equilibrium moisture content (EMC). Boards were then oriented in the longitudinal direction and machined at 900 mm (L) length, 60 mm (T) width, and 20 mm (R) thickness. Machined boards were divided into four groups, and each of them was submitted to a machining treatment. After treatments, samples for microscopy (10 mm L), roughness (50 mm L), wettability analysis (130 mm L), and coating application (630 mm L) were re-sectioned from each specimen. Samples were then coated and cross-cut in two matched samples. One section of each sample was submitted to an accelerated aging treatment and the other remained untreated before the adhesion test.

Machining treatments

Sanding, oblique cutting, peripheral, and helical planing were used to prepare the red oak surfaces prior to coating. Initially each surfacing treatment at different levels of machining parameters was analyzed separately with the purpose of selecting the best condition of each treatment for varnishing purposes. Costa sander equipped with close-coat paper-backed sanding belts was used to sanding treatment. Boards were submitted to a 100-150-grit sanding program with aluminum oxide sandpaper. Sander feeding was carried out in the fiber direction at 14 m/min feed speed. Oblique cutting was performed with Marunaka Super Meca set up with 15° oblique angle. Feed speed and cutting depth used were 65 m/min and 0.02-mm, respectively. Freshly sharpened high-speed steel knife had 32° knife angle and 58° rake angle. Peripheral planing was performed with a straight-knife cutterhead with 52 mm of cutting radius and was mounted on the horizontal shaft of a Weinig Powermat 1,000 moulder. Knife used for cutting were freshly sharpened with rake, knife and clearance angles of 25, 45 and 20°, respectively. Feed speed used was 6 m/min, which corresponded to wavelength of 1.0 mm. Rotation speed of the cutterhead was 6000 rpm with a cutting depth of 1 mm. Casadei R63 H3 24” surface planer was used to carry out the helical planing treatment at a 1 mm cutting depth. Feed speed was 5.5 m/min, which corresponds to wavelength of 1.0 mm. Rake and helix angles were 30°and 14°, respectively. Before each planing treatment, previous cuts were carried out to level samples.

Microscopic evaluation

Machined surfaces were observed with a field-emission scanning electron microscope (JSM-6360LV, JEOL) operating at an accelerating voltage of 15 kV. Two samples for each surfacing method were selected and small cubes (1 cm^3) were prepared to observe the tangential surfaces. The cubes were attached to aluminium stubs and coated with silver paint. The fibrillation level and the presence of open lumens were the parameters used to assess these surfaces.

Roughness

Surface roughness measurements were made using a Micromeasure confocal microscope. A surface of 12.5 mm (L) x 15 mm (T) was analyzed per sample by Surface Map 2.4.13 software using an acquisition frequency and a scanning rate of 30Hz and 3 mm/s, respectively. Roughness parameters were determined by Mountain Software with a cut off length of 2.5 mm combined with a Robust Gaussian filter (7). Mean surface roughness (S_a) was calculated according to ISO 4287 (8). Core roughness depth (S_k) and reduced valley depth (S_{vk}) were calculated from the Abbot curve according to ISO 13565-2 (9).

Wettability and Surface energy

Wetting analyses of machined surfaces were performed with a goniometer (FTÅ D200) at 20°C. Wetting behaviour was assessed by sessile-drop method within 8 hours following surfacing methods. Distilled water, diiodomethane and formamide were used as test liquids. Sessile droplets (2 µL) of liquids were placed with a microsyringe on the surface on each of the thirty replicate specimens per treatment. Measurements were conducted in the longitudinal direction of the fibers. Right and left angles of the drops on the surface were collected at intervals of 0.1s for a total duration of 120s for distilled water and 30s for formamide and diiodomethane liquids. Average of the contact angles was used for the calculation of surface energy by acid-base approach (10).

Coating procedure

Machined surfaces were coated within the first 6 hours following machining. Samples were kept face against face before coating application in order to minimize the risk of contamination. Three coats of a solvent-borne coating were air sprayed at room temperature according to manufacturer's specifications. Wet average thickness was 200-µm. Surfaces were sanded, lightly with 320 grit abrasive paper between the first and second coats.

Accelerated Aging

Prior to aging, samples ends were sealed with paraffin to prevent moisture exchange during treatment. Samples were then placed in a Cincinnati Sub Zero environmental stimulation chamber (WM-906-MP2H-3-SC/WC) and underwent an aging treatment which consisted of four cycles of 48h at 15% RH and 50°C followed by 48h at 90% RH and 50°C. After aging, specimens were re-conditioned at 20°C and 40% RH.

Adhesion tests

Performance of coating film adhesion from aged and unaged samples was assessed by mechanical pull-off test as described in ASTM D4541 (11). A small dolly (20 mm diameter) was glued with a two-part epoxy adhesive on each specimen and allowed to cure for 48h. A circular groove was then made around the dollies to prevent failure propagations out of the tested area. Finally, the dollies were pulled off from the substrate at constant speed in a universal testing machine. The force attained at rupture was recorded and used to calculate the pull-off strength.

Statistical analyses

Statistical analyses were done on SAS statistical package, version 9.4. Pull-off strength results were analyzed as repeated measures design with the mixed procedure. One-way analyses of variance were performed to assess surface roughness and surface energy data. Means-difference comparison tests were made when a significant effect was found at the 5% probability level.

RESULTS AND DISCUSSION

Surface topography

SEM micrographs showed differences among surfaces produced by the four surfacing methods (Figure 1). Helical and oblique-cut surfaces showed similar features. Both machining process generated surfaces with no visible defects (Figure 1A-B). Lumens and rays were visible with slightly ruptured cell walls. Also, plateau-like areas were more frequent on these surfaces than other two surfacing methods. According to some authors (12-13), these areas are probably formed during the cutting action taking place by peeling entire individual cells in, or close to, the middle lamella. Red oak surfaces prepared by peripheral planing showed a more important level of fibrillation when compared with helical planing and oblique cutting. Partial detachment of microfibrils or fibrils groups from cell walls characterized peripheral-planed surfaces (Figure 1C). Sanded surfaces had the highest level of fibrillation than other machined surfaces. Structure of wood cells on red oak surfaces were severely modified by sanding process. The presence of crushed microfibrils and torn cell walls characterized these surfaces (Figure 1D). Furthermore, abrasive grains created micro-grooves along surfaces which were partially filled with dust and damaged tissues. Fibrillation increases the actual surface available for mechanical adhesion that can improve coating bonding (14-17). However, the penetration of coatings or glues into the wood can be limited by the layer of damaged cells on surfaces (18). This suggests that a combination of open lumens and a certain level of fibrillation are desirable to improve coating spreading and perhaps its performance.

Despite of helical planing and oblique cutting had visually showed smoother surfaces than those from other two treatments (Figure 1); these surfaces presented the highest values of average surface roughness parameter (S_a) as shown in Table 1. Peripheral planing had S_a value statistically equal to those found for the processes cited above. Vessels, rays and fibers lumens were clearly visible on these surfaces which probably increased the surface roughness. Average roughness of sanded surfaces was lower and statistically different than the other three surfacing methods. As previously reported, sanded surfaces are more uniform because of the combination of cellular damage and dust filling the lumens (19). This surfacing method alters the cellular structure in such a way that no anatomical roughness is detectable (16, 20). In fact, S_a is a common roughness indicator that represents an overall measure of the texture comprising the surface. Furthermore, previous studies (21-24) have demonstrated that the characterisation of surface roughness only based on the average roughness parameter is not adequate for the evaluation of machining process on porous wood species (like red oak) because this roughness parameter is sensible to extreme values produced by the presence of vessels.

On the other hand, the lowest values of core roughness depth (S_k), which describes the processing roughness (20-21), were found for machined surfaces with helical planing and oblique cutting (Table 1). This roughness parameter reflects the actual process irregularities by showing low anatomical noise. Surfaces prepared by peripheral planing had intermediate values of S_k. The highest core roughness depth value was provided by sanding. This result can be explained by the irregularities in the surface caused by the abrasive grit particles during sanding process, which drastically change the anatomical structures increasing the roughness due to the process (21). Furthermore, the S_k results were corroborated by SEM micrographs (Figure 1), where the effect of different surfacing methods on red oak surfaces can be visualised through the assessment of cell damages in the tangential surfaces.

Samples prepared by oblique cutting, peripheral planing, and helical planing had statistically similar reduced valley depth (S_{vk}) values (Table 1). In contrast, the S_{vk} parameter was significantly lower for the sanding process. S_{vk} roughness parameter is related to wood anatomy

(22-23). This suggests that the presence of opened lumens on surfaces prepared by the three planing processes contributed to increase the S_{vk} parameter by raising the mean line of the roughness profile (19). Moreover, this result confirms the fact that sanding uniformizes the surface and minimizes the influence of wood anatomy (24).

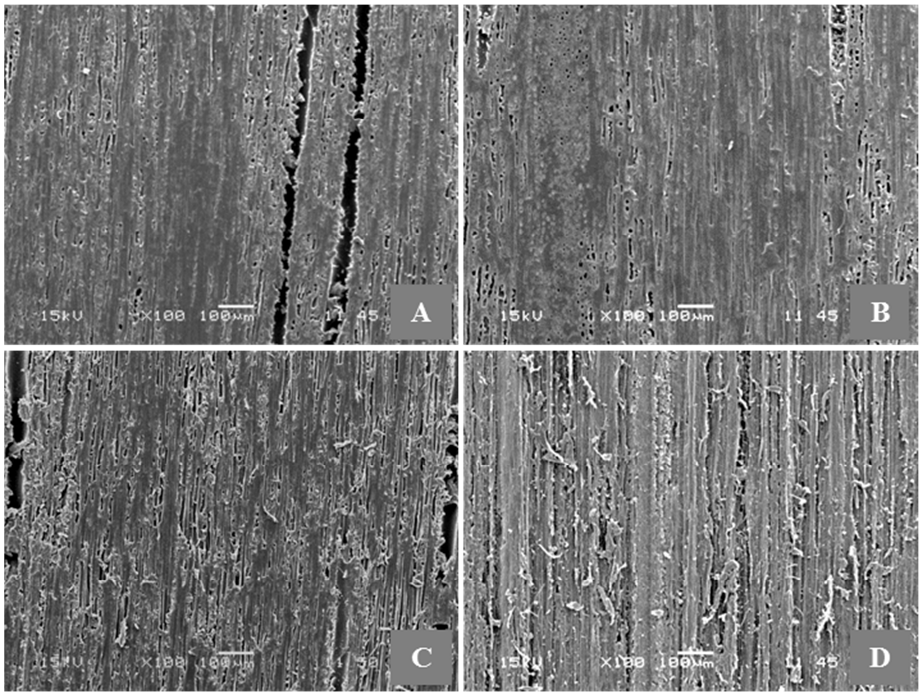


Figure 1: Tangential SEM micrographs of red oak uncoated surfaces produced by helical planing (A), oblique cutting (B), peripheral planing (C), and sanding (D).

Table 1: Surface roughness parameters of red oak wood specimens.

Surfacing method	Roughness parameters (µm)		
	S_a [1]	S_k	S_{vk}
Sanding	8.0[B2] (1.1)	14.6[A] (0.4)	38.1[B] (5.6)
Peripheral planing	15.7[A] (1.1)	9.8[B] (0.4)	97.6[A] (5.6)
Helical planing	16.2[A] (1.1)	5.1[C] (0.4)	98.6[A] (5.6)
Oblique cutting	18.7[A] (1.1)	5.1[C] (0.4)	110.9[A] (5.6)

1 S_a: mean surface roughness; S_k: core roughness depth; S_{vk}: reduced valley depth.
2 Values are means (standard errors of the means) of 30 replicates. Means within followed by the same letter are not significantly different 5% at the probability level.

Wettability

Contact angles as a function of time are presented in Figure 2. Sanding had the fastest wetting, followed by oblique cutting. Peripheral and helical planing showed similar wetting behaviour. The type of process by which wood is machined influences the structure, morphology and chemical composition of its surface, resulting in machined surfaces with different wettability properties. SEM micrographs of red oak samples confirm that sanded surfaces had the most damaged and roughened surfaces than those planed. The high level of fibrillation produced by sanding offered the best condition for water spreading on red oak surfaces. Scratches left by the abrasive grains accelerated the conduction of water by capillary action (24).

Also, the highest total surface energy (γ_s) was observed on sanded surfaces, while planed surfaces showed similar values for γ_s (Table 2). Sanded surfaces had the highest value of disperse component (γ_s^{LW}), followed by peripheral planing, helical planing, and oblique cutting (Table 2). According to Garnier and Glasser (25), γ_s^{LW} component in cellulosic materials depends mostly on the presence and concentration of free hydroxyl groups on the surface. The microfibrils detached from cell walls can increase the amount of the hydroxyl groups available on surfaces. Thus, the higher value of the disperse component on sanded surfaces could be due to the increase of hydroxyl sites exposed at the surface. A more important polar component (γ_s^{AB}) is related to hydrophilic surfaces (26). Surfaces prepared by sanding and oblique cutting presented values significantly higher of this component (γ_s^{AB}), which agrees with the findings of wetting behaviour (Figure 2). Lewis acid parameter (or electron acceptor γ_s^+) and Lewis base parameter (or electron donor γ_s^-) of surface energy can be used in treating the contribution of acidic and basic characters to the adhesion across an interface (27). γ_s^- values were much higher than those of γ_s^+ for all machining treatments (Table 2). This means that these surfaces are able to participate in polar interactions with acid materials. Sanding and oblique cutting showed similar values of both γ_s^+ and γ_s^- components, which could indicate that these surfaces may exhibit similar performance after coating.

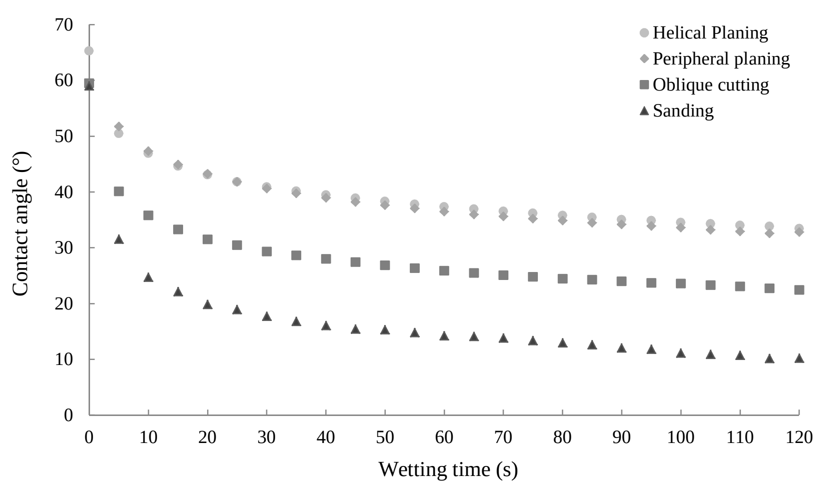


Figure 2: Dynamic contact angle changes of distilled water as a function of time on red oak samples prepared by four different surfacing methods.

Table 2: Mean difference comparisons performed on the data of surface energy components for red oak wood specimens.

Surfacing method	γ_s^{1}	γ_s^{LW}	γ_s^{AB}	γ_s^{+}	γ_s^{-}
Sanding	59.4^{A2} (0.2)	50.3^{A} (0.2)	9.1^{A} (0.3)	1.5^{B} (0.1)	16.1^{A} (1.0)
Peripheral planing	55.3^{B} (0.2)	48.1^{B} (0.2)	7.2^{C} (0.3)	2.5^{A} (0.1)	6.1^{C} (1.0)
Helical planing	54.7^{B} (0.2)	46.2^{C} (0.2)	8.5^{B} (0.3)	2.4^{A} (0.1)	9.0^{B} (1.0)
Oblique cutting	54.8^{B} (0.2)	45.3^{D} (0.2)	9.6^{A} (0.3)	1.6^{B} (0.1)	17.8^{A} (1.0)

1 $\gamma_{s:}$ total surface energy; γ_s^{LW}: disperse component; γ_s^{AB}: polar component; γ_s^{+}: electron acceptor component; γ_s^{-}: electron donor component.
2 Values are means (standard errors of the means) of 30 replicates. Means within followed by the same letter are not significantly different at the 5% probability level.

Adhesion performance

The ANOVA showed that pull-off strength was significantly affected by the interaction between surfacing method (S) and aging (A) (Table 3). The effect of the surfacing method on pull-off strength was statistically significant. However, the effect of aging on pull-off strength was statistically more pronounced (Table 3). Results of adhesion and aging tests for four surfacing methods are summarized in Table 4. Before aging, pull-off strength was statistically similar for sanding, peripheral and helical planing. The lowest pull-off adhesion measured was found on specimens planed with oblique cutting (Table 4). After aging, sanded specimens showed the highest pull-off adhesion, while planed surfaces had similar pull-off adhesion. Adhesion results agreed with findings on previous studies (28-31) which reported that fibrillation can improve the adhesion of coatings by increasing the area available for mechanical anchoring. However, the fibrillation could reduce the coating adhesion, if damaged cells are not firmly attached to the surface (31).

Loss of coating-substrate adhesion was statistically similar to specimens machined by peripheral and helical planing. Regardless the lower value of pull-off strength before aging, samples planed with oblique cutting presented loss in adhesion similar to sanding (Table 4). As mentioned before, the certain level of fibrillation presented is perhaps what has ensured a better adhesion of the coating to sanded surfaces after the accelerated aging test. The area between substrate and coating increases as surface roughness increases which could explain the better adhesion of rougher surfaces. The presence of plateau-like areas on planed surfaces with oblique cutting may have been responsible for the low value of pull-off strength before aging. However, the availability of opened lumens and rays could have increased the adhesive penetration and decreased the impact of the weathering treatment in these surfaces.

Table 3: F values for pull-off strength analysis obtained from ANOVA for red oak surfaces prepared by four different machining processes.

Source of variation	Pull-off strength
Surfacing method (S)	5.7*
Aging (A)	502.1*
S x A	11.3*

*Statistically significant at the 5 % probability level.

Table 4: Pull-off strength before and after an accelerated aging treatment of an interior coating applied on red oak wood samples.

Surfacing method	Before aging (MPa)	After aging (MPa)	Loss in adhesion (%)
Sanding	6.4^{A1} (0.3)	4.5^{A} (0.1)	29^{B} (2.4)
Peripheral planing	6.7^{A} (0.3)	3.8^{B} (0.1)	42^{A} (2.4)
Helical planing	6.9^{A} (0.3)	3.7^{B} (0.1)	40^{A} (2.4)
Oblique cutting	5.4^{B} (0.3)	3.9^{B} (0.1)	26^{B} (2.4)

1 Values are means (standard errors of the means) of 30 replicates. Means within followed by the same letter are not significantly different at the 5% probability level.

CONCLUSIONS

Helical planing and oblique cutting produced surfaces with no visible defects. Peripheral planing created slight fibrillation, while sanding produced the most cell damage on red oak surfaces. Peripheral and helical planing suffered a significant loss in adhesion after the accelerated aging. Sanded surfaces showed good wettability, high process roughness and adhesion after aging compared to other treatments. The high level of fibrillation promoted long-term adhesion strength on these surfaces. Oblique cutting caused intermediate wettability, lower process roughness and similar loss in adhesion strength to sanding, showing potential for long-term utilization and could be used as an alternative to sanding on red oak surfaces. Further research to optimize the level of fibrillation to ensure better adhesion before aging is necessary.

Acknowledgements

The assistance of Luc Germain and Daniel Bourgault in specimen preparation and testing work is gratefully acknowledged. This research was supported by the Coordination for the Improvement of Higher Education Personnel of Brazil (CAPES) and by the Natural Sciences and Engineering Research Council of Canada (NSERC).

REFERENCES

1. Taylor JB, Carrano AL, Lemaster RL (1999) Quantification of process parameters in a wood sanding operation. Forest Products Journal 49(5):41-46.
2. de Moura LF, Hernández RE (2006) Effects of abrasive mineral, grit size and feed speed on the quality of sanded surfaces of sugar maple wood. Wood Science and Technology 40(6):517-530.
3. Stewart HA (1979) Analysis of orthogonal woodcutting across the grain. Wood Science 12(1):38-44.
4. Williams SR (2010) General Technical Report FPL-GTR-190. Wood Handbook, Chapter 16: Finishing of Wood. U.S. Department of Agriculture, Forest Service, Forest Products. Madison.
5. Rowell RM (2012) Handbook of Wood Chemistry and Wood Composites, Second Edition. CRC Press. New York.
6. Freeman HA, Wangaard FF (1960) Effect of wettability of wood on glue-line behavior of two urea resins. Forest Products Journal 9(12):451-458.

7. ISO 13565-2 (1996) Geometrical product specifications (GPS). Surface texture. Profile method; Surfaces having stratified functional properties. Part 2: Height characterization using the linear material ratio curve. International Standards Organization. British Standards Institute. London.
8. ISO 4287 (1997) Geometrical Product Specifications (GPS). Surface Texture. Profile Method. Terms. Definitions and Surface Texture Parameters. International Standards Organization. British Standards Institute. London.
9. van Oss CJ, Chaudhury MK and Good RJ (1988) Interfacial Lifshitz-van der Waals and polar interactions in macroscopic systems. Chemistry Reviews 88:927-941
10. ASTM D4541 (2002) Standard test method for pull-off strength of coatings using portable adhesion testers. ASTM, Philadelphia.
11. de Moura LF, Cool J, Hernández RE (2010) Anatomical evaluation of wood surfaces produced by oblique cutting and face milling. IAWA Journal 31(1):77-88.
12. Cool J and Hernández RE (2012) Effects of peripheral planing on surface characteristics and adhesion of a waterborne acrylic coating to black spruce wood. Forest Products Journal 62:124-133.
13. de Moura LF, Hernández RE (2007) Characteristics of sugar maple wood surfaces machined with the fixed-oblique knife pressure-bar cutting system. Wood Science and Technology 41:17-29.
14. Hernández RE, Cool J (2008) Effects of cutting parameters on surface quality of paper birch wood machined across the grain with two planing techniques. Holz als Roh-und Werkststoff 66(2):147-154.
15. Hernández RE, Cool J (2008) Evaluation of three surfacing methods on paper birch wood in relation to water and solvent-borne coating performance. Wood and Fiber Science 40(3):459-469.
16. Cool J, Hernández HE (2011) Evaluation of four surfacing methods on black spruce wood in relation to poly (vinyl acetate) gluing performance. Wood and Fiber Science 43(2):194–205.
17. Richter K, Feist WC, Knaebe MT (1995) The effect of surface roughness on the performance of finishes. Part 1. Roughness characterization and stain performance. Forest Products Journal 45(7/8):91-97.
18. Fujiwara Y, Fujii Y, Okumura S (2003) Effect of removal of deep valleys on the evaluation of machined surfaces of wood. Forest Products Journal 53:58-62.
19. Gurau L, Mansfield-Williams H, Irle M (2005) The influence of wood anatomy on evaluating the roughness of sanded solid wood. Journal of Institute of Wood Science 17(2):65-74.
20. Westkämper E, Riegel A (1993) Qualitätskriterien fur Geschlieffene Massivholzoberflächen. Holz als Roh-und Werkstoff 51(2):121-125.
21. Tan PL, Sharif S, Sudin I (2012) Roughness models for sanded wood surfaces. Wood Science and Technology 46:129-142.
22. Gurau L (2014) The influence of earlywood and latewood upon the processing roughness parameters at sanding. Revista Stiintifica in Domeniul Ingineriei Lemnului 10(3):26-23.
23. Hernández H, Cool J (2007) Evaluation of water and solvent-borne coating performance for three surfacing methods on paper birch wood. Proceedings of the Third International Symposium on Wood Machining, Lausanne, Switzerland, pp 55-58.
24. de Moura LF, Hernández RE (2006) Effects of abrasive mineral, grit size and feed speed on the quality of sanded surfaces of sugar maple wood. Wood Science and Technology 40(6):517-530.
25. Garnier G, Glasser WG (1996) Measuring the surface energies of spherical cellulose beads by inverse gas chromatography. Polymers Engineering and Science 36(6): 885-894.
26. Gindl W, Schoberl T, Jeronimidis G (2004) The interphase in phenol-formaldehyde and polymeric methylene diphenyl-di-isocyanate glue lines in wood. International Journal Adhesion Adhesives 24(4): 279-286.

27. Good RJ (1992) Contact angle, wetting, and adhesion: A critical review. Journal Adhesive Science and Technology 6(12): 1269-1302.
28. de Moura LF, Hernández RE (2005) Evaluation of varnish coating performance for two surfacing methods on sugar maple wood. Wood and Fiber Science 37(2):355-366.
29. de Moura LF, Hernández RE (2006) Effects of abrasive mineral, grit size and feed speed on the quality of sanded surfaces of sugar maple wood. Wood Science and Technology 40(6): 517-530.
30. de Moura LF, Hernández RE (2006) Evaluation of varnish coating performance for three surfacing methods on sugar maple wood. Forest Products Journal 56 (11/12):130-136.
31. Cool J, Hernández RE (2011) Performance of three alternative surfacing processes on black spruce wood surfaces in relation to water based coating adhesion. Wood and Fiber Science 43(4):365–378.

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
PRO LIGNO
www.proligno.ro
Vol. 11 N° 4 2015
pp. 516-524

THE INFLUENCE OF SOME FACTORS ON CUTTING FORCE AND SURFACE ROUGHNESS OF WOOD AFTER SANDING

Ľubomír JAVOREK
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 546, Fax: ++421 45 5320015, E-mail: lubomir.javorek@tuzvo.sk

Jozef KÚDELA
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 334 Fax: ++421 45 5320015, E-mail: jozef.kudela@tuzvo.sk

Ján SVOREŇ
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 548, Fax: ++421 45 5320015, E-mail: jan.svoren@tuzvo.sk

Mária KRAJČOVIČOVÁ
Technical University in Zvolen
T. G. Masaryka 24, 960 53 Zvolen, Slovak rep.
++421 45 5206 575, Fax: ++421 45 5320015, E-mail: maria.krajcovicova@tuzvo.sk

Abstract

This contribution presents results of an experimental research on sanding. With a sample of oak being the experimental material, sanding was carried out on radial, tangential and transversal surface of the piece. The impact force was changed on three levels (21 N, 41 N and 58.5 N), the grain size of sanding belt in four levels (40, 60, 80, 100). The constant parameters were: cutting speed 200 $m{\cdot}min^{-1}$, moisture content of the sample 12%. The cutting force and surface roughness were measured and cutting force was recaltutated to 1 mm of wideness of sanding belt. The cutting force was: within 0.80 till 1.0 $N{\cdot}mm^{-1}$ for oak, impact force 21 N, for all surfaces and for all grain size; within 0.47 till 0.54 $N{\cdot}mm^{-1}$ for oak, impact force 41 N, for all surfaces and for all grain size; within 0.23 till 0.26 $N{\cdot}mm^{-1}$ for oak, impact force 58.5 N, for all surfaces and for all grain size. Surface roughness alternated within limits 4.42 μm – 14.43 μm depending up grain size, impact force and character of sanded surface. The minimum valids for grain size 100, transversal surface and impact force 21 N; maximum valids for grain size 40, tangential surface and impact force 41 N. Surface roughness was measured in perpendicular direction to cutting direction.

Key words: *sanding of wood; impact force; cutting force; surface roughness.*

INTRODUCTION

Sanding of wood is a very frequent object of reaserch in the word. The reason is that sanding is usually the last operation of surface modification before lackering or painting and the technology may improve surface quality and ensure dimensional accuracy of worpiece. The quality of sanding surface directly determinates the final effect: as for as both the potential customer's interest (i.e. the succes on the market) and the resistance against weather conditions are concerned.

Sanding can be charakterized as machining with a lot of cutting wedges with non-defined geometry. This geometry is coined by grains of the abrasive material, joined together by means of a binding material.

In generaly, the rake angle of grains is crushingly negative, the chip is modified under a big angle φ_1 in the zone of machining and the temperature in this area may rise, by **Banský, Naščák, Wieloch** (1999), up to 230°C; They tested the influence of temperature and grain size (P80 and P120) on the surface roughness of the chipboard and MDF board. The influence of temperature on the surface roughness was the most intensive for grain size P80.

The significance of sanding technology arises together with the evolution and production more and more productive grinders and the original purpose sanding machine for finishing is extended for roughness too. In this case, sanding may compete with other metods of machining.

The main characteristics of sanding according to **Driensky** (1986) are:

- irregular stylus fillet,
- irregular geometrical shape,
- high hardness and termical resistance,
- high cutting speed (from 30 mps until 120 mps,
- short-lasting contact with the machined workpiece (cca 0,0001 s),
- small size of grains (from 0,003 mm to 3 mm),
- very small cross section of the chip (from 10^{-3} mm^2 until 10^{-5} mm^2),
- wearing of grains during the sanding process, i.e. degresion of the cutting property.

A model of the chip removing including a definition of the basic geometry according to **Maslov** (1979) is displayed in Fig. 1.

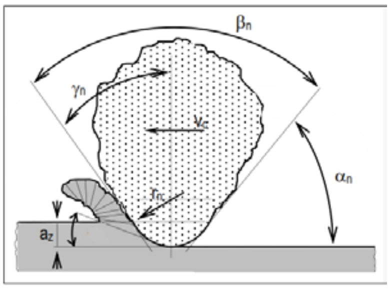


Fig. 1.
Model of the chip removing (Maslov 1979)

α_n – clereance angle, β_n – wedge angle, γ_n – rake angle, r_n – radius of cutting wedge, ϕ – angle of the primary plastic deformation, a_z – depth of the grain penetration into the material, v_c – cutting speed

Influence of the grain size on the surface roughness was in focus of **Bahchevandziev a Manev** (1999) who used a chip board covered with veneer from beech and pine as their experimental material. The granularity of abrasive papers were P100 and P150, respectively P120, P150, P180 and sanding was carried out in parallel and vertically compared with fibres. The experiment confirmed significant influence of last sanding direction to final surface roughness.

Očkajova and Siklienka (2000) solved influence of the wood species, orientation of wood's fibres, and sort of the grinding material on the volume of wood removed per minuta. They stated a correlation between removed material and species of wood, grain size, as well as fibre of wood orientation.

The research objective of **Ayrilmis, Candan, Akbulut, Balkiz** (2010) was to investigate the effects of sanding on the surface properties of the medium density fiberboard (MDF) panels made from Rhododendron ponticum L. wood. The MDF panels were sanded with different sizes of the sand paper grit: P60; P60+P80; or P60+P80+P120 grit. Surface absorption and surface roughness of the MDF panels were determined on the basis of the EN 382-1 standard and ISO 4287 by using a fine stylus profi lometer. The MDF surface sanded with a 60-grit size had a lower contact angle and more wettable surface compared to the surfaces sanded with P60+P80+P120 grit sizes.

The paper by **Fotin, Cismaru, Marthy, Brenci, Coseranu** (2011) presents the results of experimental research studies dealing with the power consumption during the process of sanding birch wood with grain sizes of P60, P80, P100 and P120 with regard to three processing directions (parallel, perpendicular and at 45º angle to the wood structure orientation). The industrial experiments were performed at NIKMOB Company, on the wide belt sander machine using an electronic device and a data acquisition logger in order to record the power consumption. The factorial experiment with two variables (feed speed and cutting depth) was used.

Fotin et al. (2013) presented results of the experimental research on the quality of birch wood surfaces after sanding them with P60, P80, P100 and P120 grains sizes, analyzing the roughness parameters of the sanded surfaces in each phase. The birch wood specimens were sanded parallelly, perpendicularly and with a 45-degrees inclination towards the wood fibres.

The paper by **Jaić, Palija, Dobić** (2010) presents a research of the influence of the system of surface finishing on the most significant decorative properties of the dried film: color and gloss. The samples were made from two species of Paulownia (Paulownia elongata and Paulownia fortunei).

In the study by **Richter, Feist, Knaebe** (1995), analysis results of a relationship between the morphological structure of the outside wood layer (surface roughness), and the performance of coatings are given. The surface roughness of five roughness categories (processed by planing, sanding, and bandsawing) on three wood substrates (vertical- and flat-grained western redcedar and flat-grained southern yellow pine) was determined by stylus tracer measurements.

The aim of the reasearch of **Tian** and **Li** (2014) was to explore the correlation between the sanding efficiency and the surface quality. As testing material were used Manchurian ash, Birch and MDF board, technological conditions were in longitudinal and transverse direction to wood fibres and grain sizes of paper P60 and P100 as influencing factors, analyzed their influence on the sanding efficiency and the surface quality. Results indicated that the highest sanding efficiency was obtained by MDF when sanded with the P60 grain size abrasive belt, Manchurian ash acquired the lowest sanding efficiency when sanded with the P100 grain size abrasive belt in longitudinal direction. Moreover, the lowest Ra was yielded by Manchurian ash when sanded with the P100 grain size abrasive belt in transverse direction; MDF gained the highest Ra when sanded with the P60 grain size abrasive belt. It also could be noted that there was not a visible correlation between sanding efficiency and surface quality in all cases of the study, but the belt should be replaced when the material removal rate decreased to a certain level in order to acquire better product quality and economic efficiency.

Sanding of non- and hydro-thermally treated oak was in the focus of experiments by **Wilkowski et al.** (2011). They used an equipment with a loaf grinding bit, and a CNC machine with vaccum clamping system for fixing of worpiece. For wood machining, following parameters were used: granulation of abrasive paper P40, dimensions of grinding bit 30mm/60mm, depth of cut 1mm, feed speed 1mpm and rotational spindle speed 2000rpm.

The experimental results from sanding different wood species (conifers, broadleaves) with known internal anatomical characteristics were used in the experiment by **Magoss** (2013): 4 different grain sizes were applied in the range of P80 and P240 were presented in diagrams showing the basic relationships between the surface roughness parameters and grain diameters (4 different grain sizes), the roughness parameters and structure number for all wood species, and internal relationships between roughness parameters.

According to **Gurau** (2013) and **Gurau** (2014) sanded wood surface have different irregularities caused by machining and wood anatomy; the wood anatomy was excluded from the roughness profiles using a method based on the Abbot-curve. Latewood was smoother than earlywood with the greatest ratio in oak, followed by spruce and beech. The author used paper with P180 and P120 grain sizes, diferent for various samples.

The effects of wood dust on humen health were analysed by **Darii and Badescu** (2011). Spruce, beech and MDF were used as experimental materials, cutting speed was constant (18 mps) and granulity of used papers was P40, P60, P80, P100 P150. From all the parameters the feed speed, pressure, moisture content and density of the material have a considerable influence on the resulted volume of chips.

The influence of the impact force (21 N, 41 N and 58.5N), feed speed (50mpm, 150 mpm, 200 mpm), sample of wood (spruce, oak, beech), type of the surface (radial, tangential, transversal), and size of the grids (P40, P60, P80, P100) on the cutting force and surface roughness were in focus of **Šuniar** and **Javorek** (2013) research. In this research, 648 pieces for every wood species were used, i.e. 1944 pieces altogether. This paper presents a reduced overview of the research – for oak, cutting speed 200 mpm only.

OBJECTIVE

The main objective of the presented research was to evaluate cutting force and surface roughness as functions of the cutting speed, impact force, species of wood and sanding direction in the face of wood's fibres orientation.

MATERIAL, METHOD, EQUIPMENT

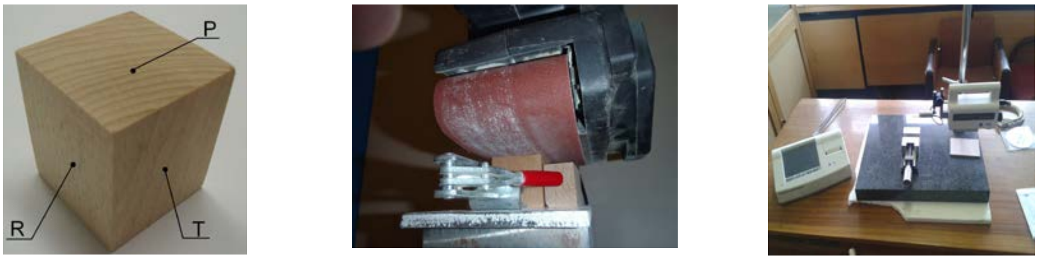
English oak (*Quercus robur* L.) was used as experimental material. The samples were prepared as a box of 60 mm x 60 mm x 60 mm so, that its sides functioned as radial, tangential and transversal surfaces. Oak is one of the most important hard wood species in Slovakia (preceded by beech and followed by maple); at present it covers app. 10.7 % of the Slovak forest area. **Klement et al** (2011) declares physical properties of the raw material with moisture content 12%. Some of the properties are shown in the Table 1.

Table 1

Physical properties of the experimental material

Density [kg.m^{-3}]		Moisture content of green wood [%]		Fibre-saturation point humidity [%]
in absolute dry status ρ_0	reduced in fresh status $\rho_{r\check{c}}$	sapwood	adult wood	
390 / 650 / 930	550	70 - 100	60 - 90	32 - 35
	Linear shrinkage in direction			Volumetric shrinkage
	longitudinal	radial	tangential	
	0.4	4.0	7.8	12.2

The goal of the experiment was to state the influence of grain size (P40, P60, P80, P100), impact force, (*21 N, 41 N, 58.5N)*, cutting speed (200 mpm), and feed direction toward to wood's fibres (parallel or perpendicular) on the cutting force and surface roughness. The surfaces of the experimental samples were defined as tangential (T), radial (R) and transversal (P).



a ***b*** ***c***

Fig. 2.
a - Definition of machined surfaces; b - Detail of sanding; c - Surface roughness measuring

Piezoelectric measuring sytem (Fig. 3.) made by Kistler (Kistler Instrumente AG, Switzerland) was used for measuring the cutting force. The system was also used for checking the impact force. The basic parts of the system were:

1. Dynamometer 9275B (parameter see Table 2).
2. Multichanel Charge Amplifier 5070A.
3. A/D Converter – DAQ System 5657A1.
4. PC + softver DynoWare.

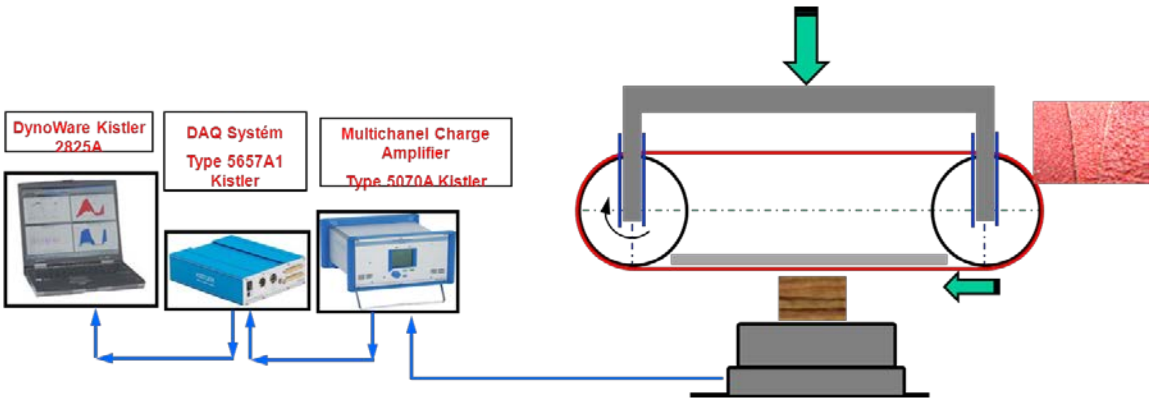


Fig. 3.
Scheme of the measuring chain

Table 2

Dynamometer typ 9257A – chosen technical parameters

Range force application	F_x, F_y, F_z	kN	– 5 ... 5
Overload	F_x, F_y, F_z	kN	–7,5 / 7,5
F_x and F_y ≤0,5 F_z	F_z	kN	–7,5 / 15
Response threshold		N	< 0,01
Sensitivity	F_x, F_y	pC/N	≈ –7,5
	F_z	pC/N	≈ –3,7
Linearity (all ranges)		% FSO	≤ ±1
Rigidity	c_x, c_y	kN/μm	>1
	c_z	kN/μm	>2
Natural frequency	f_n (x, y, z)	kHz	≈3,5
Natural frequency (mounted on flanges)	f_n (x, y)	kHz	≈2,3
	f_n (z)	kHz	≈3,5
Operating temperature range		°C	0 …70
Temperature coefficient of sensitivity		% / °C	– 0,02
Capacitance (of channel)		pF	220
Ground insulation		Ω	>10^8

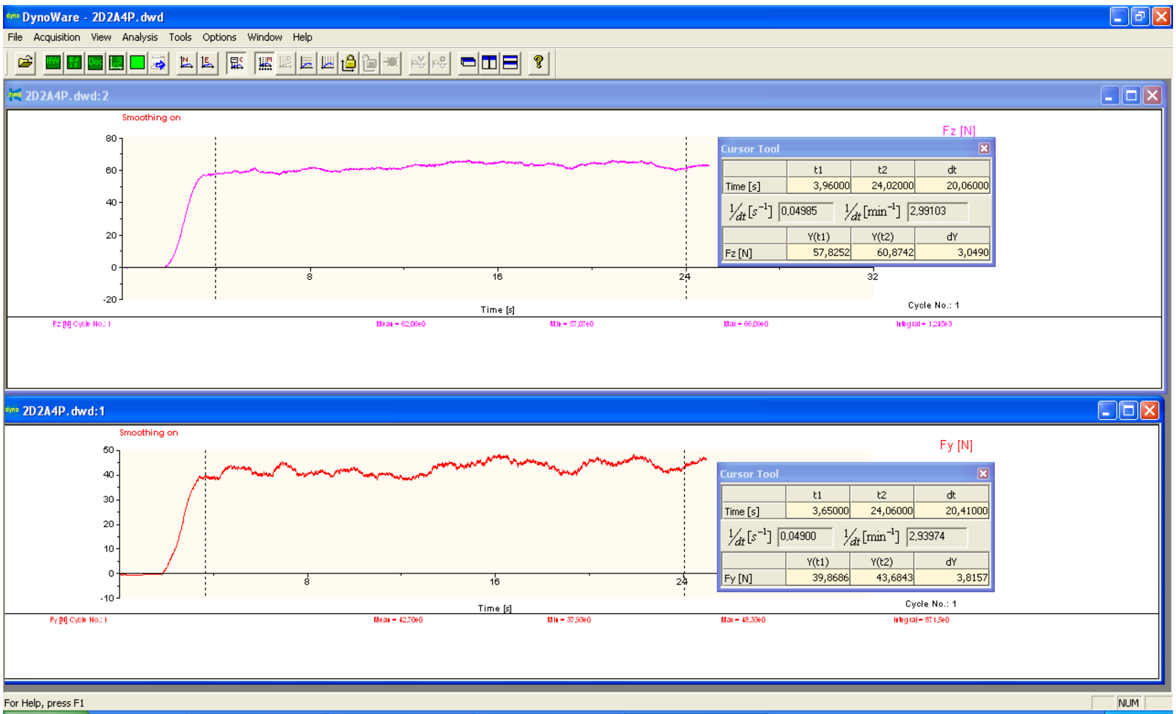


Fig. 4.
The records of the impact force (Fz) and cutting force (Fy)

RESULTS AND DISCUSSION

A fullfactorial experiment was carried out, i.e. for all variations of all independed variables. Involved results valid for one-factorial analyse. Cutting force was recalculated to 1mm-wide sanded surface, therefore quoted unit of force is N·mm^{-1}. The surface roughness was measured in the direction of cutting speed and in the direction perpendicular to cutting speed.

Fig. 5 displays the influence of impact force (A=58.5N), grain size of belts and type of the surface (R, T, P) on the cutting force. The values of forces for radial and tangential surfaces are very similar – only for grain size 40, there is a diference of 0.12N·mm^{-1}. It looks like very small, but for a 300 mm-wide board, for instance, it is 36 N, and for a 1000 mm-wide bioboard it is 120N. Therefore it is important to bear in mind this fact when processing wider plates.

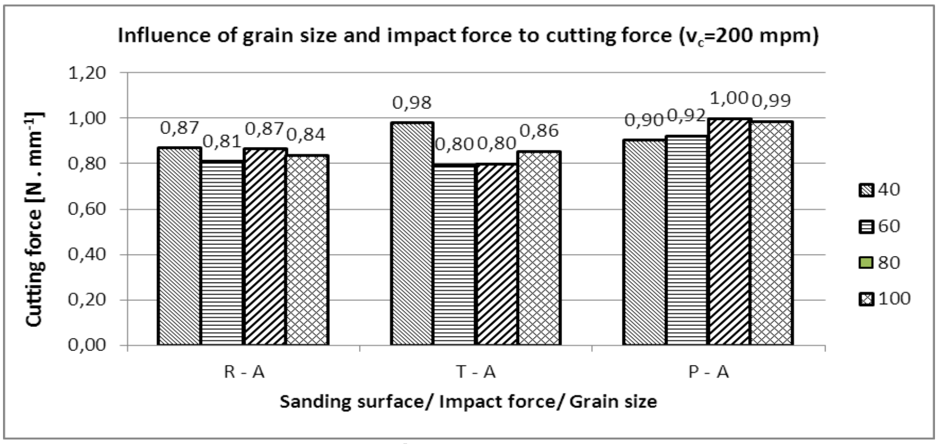


Fig. 5.
Influence of grain size and impact force A on the cutting force (oak, v_c = 200 mpm)

Values in the graph in Fig. 6 display analogical independed variables as the graph in Fig. 5. Nevertheless, the value of impact force was B=41 N, i.e 1.4-time lower. The graphs look similar but the value of cutting force was lower by 40% till 50%.

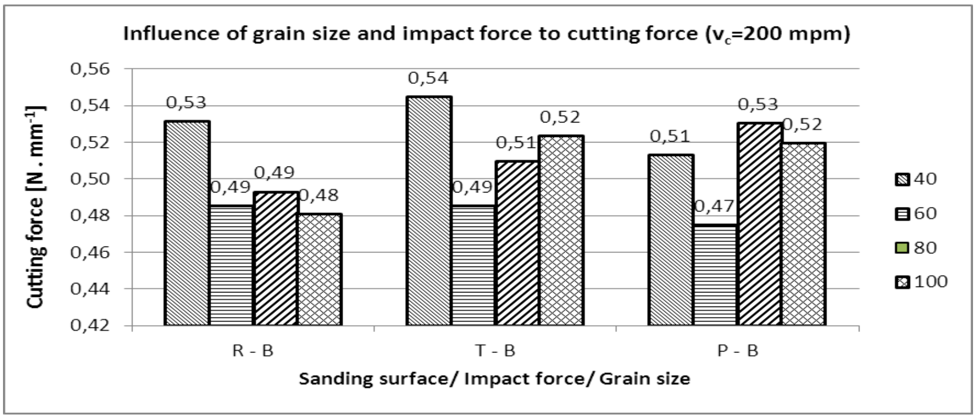


Fig. 6.
Influence of grain size and impact force B on the cutting force (oak, v_c = 200 mpm)

The graph in Fig. 7 illustrates results received during sanding with impact force C=21 N, i.e. 2.7-times smaller than force A and 2-times smaller than force B. This is evident in the decrease of the cutting force. However, if we compare radial, tangential and transversal surfaces, the cutting force increases practicaly in every case.

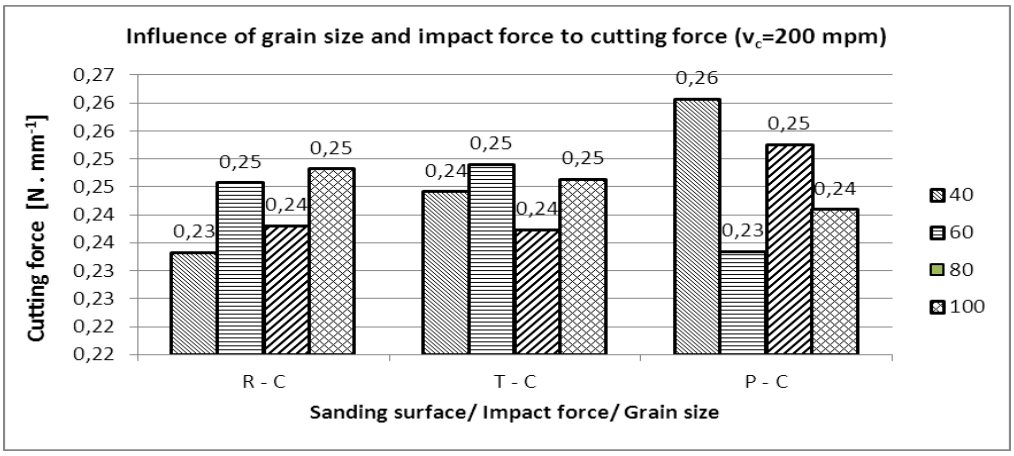


Fig. 7.
Influence of grain size and impact force C on the cutting force (oak, v_c = 200 mpm)

The evaluation of surface roughness is in follows part; as arithmetic average of absolute values, i.e. parameter Ra. For measuring the surface roughness, Surfcom 130A was used; contact measuring system with radius of stylus tip 2±0.5μm, cut-off was 0.8mm, evaluated length 30mm. The influence of the measure direction was very significant (see records in Fig. 8. resp. in Fig. 9.). Values for perpendicular direction were cca 2.5-times higher. (This paper only presents results from perpendicular direction measuring).

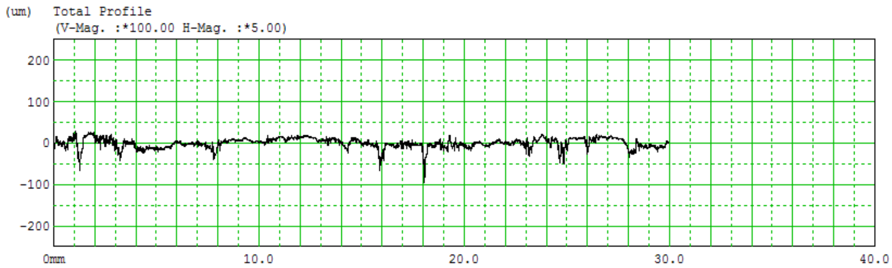


Fig. 8. Surface roughness in direction to sanding direction

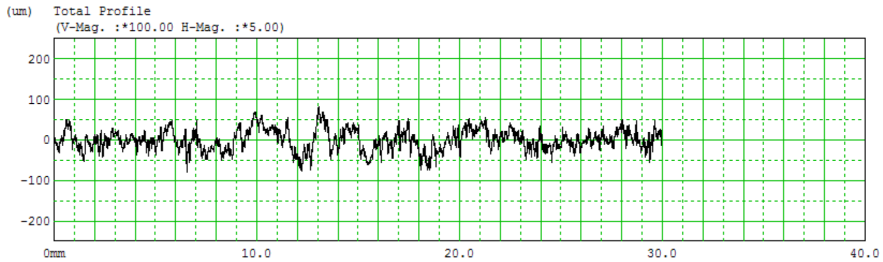


Fig. 9.
Surface roughness in perpendicular direction to sanding direction

The graph in Fig.10. presents the average values of surface roughnes as dependent on impact force, type of surface and grain size of oak.

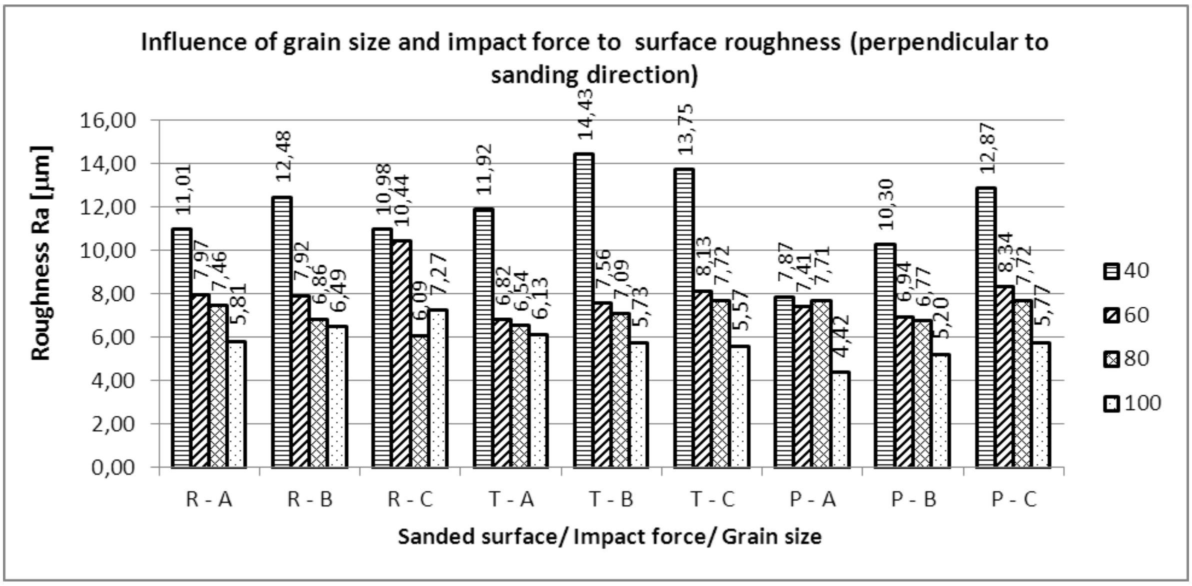


Fig. 10.
Influence of grain size, impact force and sanded surface on the surface roughness in direction perpendicular to cutting direction (oak, v_c = 200 mpm)

From this graph, a very considerable influence of grain size on the value of roughness is evident. It was true of the whole research. For example, for radial surface applies that the change granularity from 1P00 to P40 surface roughness will change (increase) in 89.5% (for force A), in 92.3% (for force B), in 51% (for force C). The average value is nearly 77.2%.

For tangential surface it is (the change granularity from P100 to P40) roughness will increase in 94.4% (for force A), in 151% (for force B), in 146% (for force C). The average value is practically 130.5%.

For transversal surface for the same granularity (P100 or P40) roughness will increase in 78% (for force A), in 98% (for force B), in 123% (for force C). The average value is almost 100%.

CONCLUSIONS

The experiment confirmed the dependency of the cutting force on grain size, impact force and fibres orientation compared with direct of cutting velocity, including the type of the sanded surface (radial, tangential, transversal). These differences of force were not very considerable.

Surface roughness very significantly depends on grain size and impact force. Surface roughness has effect on the speed of liquid interpenetration to wood.

ACKNOWLEDGEMENT

1. Part of this article was created within the framework of Grand project No. 1/0893/13 Surface facilities and interaction in interface of phases wood - liquid as result of author's research activity with widespread favour of agency VEGA-SR. Supervisior: Jozef Kúdela.

2. Experimental devices used for forces measuring were obtained with strong support of The Ministry of Education, Science, Research and Sport of the Slovak Republic and while solution of programme OPVaV-2009/5.1/03-SORO, Research and Development, Axe 5.1 Building of infrastructure of higher schools and modernization of their interior equipment with a view to improve the conditions of the education process.

REFERENCES

Ayrilmis N et al. (2010) Effect of Sanding on Surface Properties of Medium Density Fiberboard. Drvna Industrija 61(3):175-181. http://drvnaindustrija.sumfak.hr/pdf/Drv/20Ind/20Vol/2061/203/20Ayirlmis.pdf. (acces 2015-02-27)

Bahchevandziev K, Manev T (1999) Effects of sanding and staining on the surface quality of veneered boards. In. Zborník referátov z medzinárodnej vedeckej konferencie "Stroj-Nástroj-Obrobok", Nitra, pp. 7-11.

Banský M et al. (1999) The testing of sanding papers from point of their durability. (In Slovak: Testovanie brúsnych papierov z hľadiska ich životnosti.) In. Zborník referátov z medzinárodnej vedeckej konferencie "Stroj-Nástroj-Obrobok", Nitra, pp.19-22.

Darii I, Badescu LAM (2011) Research on the emission of dust resulting from sanding process for solid Spruce, Beech and MDF panel. In: Recent Advances in Environment, Energy Systems and Naval Science. WSEAS Press, 2011. ISBN 978-1-61804-032-9, pp. 288-296.

Csiha C (2004) Study of wod surface roughnesson P and r profile pocused on big poroused species. Doctoral thesis. University of West Hungary. Sopron. http://ilex.efe.hu/PhD/fmk/csihacs/tz_en1005.pdf, (acces 2015-02-27)

Driensky D et al. (1986) Strojní obrábění I. SNTL Praha. Pp. 422, ISBN 04-238-86.

Fotin A et al. (2011) Experimental research concerning the power consumtion during the sanding process of birch wood. In. 2011Proceedinngs of International conference of scientific paper. Afases, Brasov, 26-28 May. Pp. 771-778. http://www.afahc.ro/ro/afases/2011/eng/4.2/FOTIN_Cismaru_Marthy_Brenci_Cosereanu.pdf. (acces 2015-02-27)

Fotin A et al. (2013) Influence of the processing parameters upon the birch wood sanded surfaces. In.: PRO LIGNO, 9(4):760-770, Issn 2069-7430, ISSN-l 1841-4737.http://www.proligno.ro/ro/articles/2013/4/Fotin_final.pdf (acces 2015-02-27)

Gurau L (2013) Analyses of roughness of sanded oak and beech surface. PRO LIGNO, 9(4):741-750, ISSN 2069-7430

Gurau L (2014) The influence of aerywood and late wood upon the processing roughness parameters at sanding. PRO LIGNO, 10(3):26-33, ISSN 2069-7430

Hiziroglu S (1996) Surface Roughness analysis of wood composites: A stylus Method. Forest Products J. 46(7/8):67-72.

Jaić M et al. (2010) The influence of surface finishing of paulownia siebold et zucc. on the decorative properties of lacquered surface.http://idk.org.rs/wp-content/uploads/2015/01/2-2014/Jaic%20rad.pdf (acces 2015-02-27)

Klement I et al. (2011) Dub letný. In: Základné charakteristiky lesných drevín – spracovanie drevnej suroviny v odvetví spracovania dreva. Národné Lesnícke Centrum, pp.82 ISBN 978-80-8093-112-4. http://www.nlcsk.sk/files/1708.pdf. (acces 2015-02-27)

Magoss E (2013) General regularities of the surface roughness sanding solid woods. In Proceedings 21st IWMS Tsukuba, Japan, Pp. 325-332.

Maslov JN (1979) Teorie broušení kovů. (Theory of metal sanding). SNTL Praha. pp. 248. 04-225-79.

Očkajová A, Siklienka M (2000) The influence of chosen factors of wood sanding upon the efficiency of sand belt. In: Wood Research. 45(2):33-38.

Richter K et al. (1995) The effect of surface roughness on the performance of finishes. Part 1. Roughness characterization and stain performance. Forest Product J. V. 45, 7/8. http://www.fpl.fs.fed.us/documnts/pdf1995/richt95a.pdf. (acces 2015-02-27)

Schultz MP (2002) The Relationship Between Frictional Resistance and Roughness for Surfaces Smoothed by Sanding. Department of Naval Architecture & Ocean. Engineering, United States Naval Academy, Annapolis, MD 21402. http://www.dtic.mil/dtic/tr/fulltext/u2/a575300.pdf. (acces 2015-02-27)

Šuniar P (2013) The influence of choosen factors to forces factors and surface quality during sanding. (In Slovak: Vplyv vybraných faktorov na silové parametre a kvalitu povrchu pri brúsení). Diploma thesis. Technical University in Zvolen. Faculty of Environmental and Manufacturing Technology. Pp73. Supervisior: Ľubomír Javorek.

Tian M, Li L (2014) Study on influencing factors of sanding efficiency of abrasive belts in wood materials sanding. In.: Wood Research 59(5):835-842. http://www.centrumdp.sk/wr/201405/20140512.pdf. (acces 2015-02-27)

Wilkowski J et al. (2011) Surface roughness after sanding of thermally modified oak wood. In. Annals of Warsaw University of Life Sciences – SGGW. Forestry and Wood Technology No 76, 2011: 208-211. http://annals-wuls.sggw.pl/files/files/fwt/fwt2011no76art42.pdf. (acces 2015-02-27).